

# **Clouds and the Earth's Radiant Energy System (CERES)**

## **Validation Document**

### **Imager Clear-Sky Determination**

### **and Cloud Detection**

### **(Subsystem 4.1)**

Ronald M. Welch<sup>1</sup>

Bryan A. Baum<sup>2</sup>

<sup>1</sup>Institute of Atmospheric Sciences  
South Dakota School of Mines and Technology  
Rapid City, SD 57701-3995

<sup>2</sup>Atmospheric Sciences Division  
NASA Langley Research Center  
Hampton, VA 23681-0001

## **4.1.1 Introduction**

### **4.1.1.1 Measurement and Science Objectives**

This document proposes a strategy for addressing the verification of cloud properties from EOS imager data, specifically clear-sky determination and cloud detection/masking. The methodology for this task is presented in Baum et al. (1995). CERES cloud retrieval algorithms are currently in development using data from the Advanced Very High Resolution Radiometer (AVHRR, 1.1 or 4-km resolution at nadir), the High Resolution Infrared Radiometer Sounder (HIRS, 17.4-km resolution at nadir), and various geostationary platforms such as the Geostationary Orbiting Environmental Satellite (GOES; 1-km visible, 4-km infrared). Beginning with the launch of the Tropical Rainfall Measuring Mission (TRMM) in 1997, the CERES algorithms will be applied to data from new imagers, including the Visible-Infrared Radiometer (VIRS, 2-km resolution) and the Moderate Resolution Imaging Spectroradiometer (MODIS; 0.25, 0.5, and 1-km resolution). While we designed the CERES cloud algorithm to have as input any imager data, a number of questions remain as to how consistent the cloud retrievals are between the various imagers. Besides the differences in spectral channels between imagers, there also is a difference in pixel resolution to consider. In the following sections, we propose a number of strategies, in order of priority, for verifying the horizontal cloud boundaries. By contrast, the validation plan for section 4.2 considers the validation of cloud boundaries in the vertical dimension, i.e., with height.

### **4.1.2.2 Missions**

The first launch of the CERES instrument is on the Tropical Rainfall Measuring Mission (TRMM) in 1997. In 1998, CERES will launch on the EOS-AM-1 platform, followed by EOS-AM-2. Follow-on missions to TRMM and EOS-AM and EOS-PM are currently planned. The CERES algorithms will be applied to data from new imagers, including the Visible-Infrared Radiometer (VIRS) and the Moderate Resolution Imaging Spectroradiometer (MODIS).

### **4.1.2.3 Science data products**

The cloud properties generated from imager data in CERES Subsystem 4.1, 4.2 and 4.3 will be convolved with CERES broadband radiometric data and saved in the CERES SSF product.

## 4.1.2 Validation Criterion

### 4.1.2.1 Overall approach

Our validation strategy involves two key elements. First, our retrieved clear-sky and cloud properties must be consistent globally for both daytime and nighttime conditions. Second, assuming that our clear-sky and cloud properties are consistent and reasonable on a global scale, we need to verify that the results compare well with independent observations from ground-, air-, and other satellite-based observations.

Several methods are available for implementing steps to address the first key element. Proof of consistency may be found, for example, from inspection of global maps of derived clear-sky and cloud parameters, from comparison with previous results for some specified time period, or by comparison with other global clear-sky and cloud products such as the International Satellite Cloud Climatology Project (ISCCP) or Clouds from AVHRR (CLAVR). It is our experience that inspection of raw imagery and global clear-sky and cloud property maps, especially during the initial processing stages, tends to uncover a multitude of problems. While some problems may be easily tracked down, others may indicate more subtle algorithm implementation problems. Each imager has idiosyncronies that take time to understand. Once the imager is better understood, software needs to be developed and implemented to work around those idiosyncronies. Globa, gridded clear-sky and cloud products may be generated automatically during processing. TO some degree, comparison with time histories of previously generated results also may be automated. Comparison with other data sets such as ISCCP or CLAVR are more time intensive, especially concerning the interpretation of differences between various data sets (both different years and different sensors).

Once the behavior of the imager used to develop CERES clear-sky and cloud properties is understood and the retrieved clear-sky and cloud properties seem to be consistent globally, comparison of cloud oundaries will be made with independent observations. Comparison of satellite-retrieved cloud properties with ground-based observations should be performed over a long time period for a number of regions, as we discuss later in this document.

### 4.1.2.2 Sampling requirements and trade-offs

We will organize the satellite cloud cover retrievals according to recognized global cloud climatological regions and according to surface types. Cloud detection is much easier over a dark, uniform ocean surface than over bright, high contrast surfaces such as ice/snow and deserts. For a first cut at relevant cloud conditions, we define the following categories:

- a. Global cloud climatologies: There are 29 recognized cloud climatologies (Sherr et al. 1968) between 70N and 70S, as described in Table 1 (at end of this document). An additional 11 cloud climatologies are selected from the Arctic and Antarctic regions.
- b. Surface types: ocean (tropics, midlatitude, and polar), vegetated land (tropics, midlatitude and polar, including tundra), non-vegetated land (deserts, other), mountains, snow-covered land (midlatitude and polar) and ice-covered water (sea ice and fresh water ice).

c. Seasons: summer, winter and transitional.

d. Day/night: Daytime conditions are defined as having solar zenith angles less than  $85^\circ$ . For twilight conditions, the nighttime algorithm is applied. Sunlint is included in the daytime conditions.

For each of the 40 global cloud climatologies, it is assumed that there are, on average, two surface types present. Therefore, there are a total of  $40 * 2 * 3 * 2 = 360$  conditions (sunlint included). We further assume that we need 100 independent samples for each of these conditions, for a total of 36,000 samples. Many of these samples should include high spatial resolution Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) global data for validation. For the ASTER validation data set, we can reduce the number of samples to  $40 \text{ climatologies} * 2 \text{ (day/night)} * 100 \text{ independent samples} = 8000$  ASTER scenes (60 km x 60 km). ASTER has three visible channels, six near-infrared channels and five infrared channels. The spatial resolution of these channels is 15m, 30m and 90m, respectively. ASTER will be on the EOS-AM platform. Studies using ASTER would be similar to that of Wielicki and Parker (1992), but extended to many of the cloud regimes where independent observations of cloud cover are sparse.

#### 4.1.2.3 Measures of Success

The CERES cloud retrieval team intends to determine whether each satellite imager (i.e., AVHRR, MODIS, VIRS) pixel is clear-sky, single-layered cloud or multiple-layered cloud. The multilayered cloud algorithm is described in subsystem 4.2. Our best estimate of the accuracy of the current clear-sky/cloud detection algorithms is on the order of 90%. The goal is 95% accuracy on a global basis.

The current clear-sky/cloud detection algorithms have been designed for specific regions, most notably polar, desert, regions of extensive biomass burning, and general global. Previous global cloud masking algorithms, such as ISCCP and CLAVR, generally have avoided sunlint regions. However, the present algorithms no longer have this restriction. Optically thick clouds generally are detected with high accuracy over any surface, and most clouds are discriminated well for low brightness, low contrast water surfaces. However, cirrus cloud detection and sub-pixel scale cloudiness is much more difficult to detect.

### 4.1.3 Pre-launch Algorithm Test/Development

#### 4.1.3.1 Field experiments and global studies

In Section 4.1.2.1, we mentioned that the first step in the process of verification is to make certain that the global cloud properties are consistent on a global scale for both daytime and nighttime cases. Some basic questions are listed below:

1. Are cloud boundaries continuous moving from day to night?
2. Are cloud covers consistent both at nadir and at high-viewing angles?
3. Are there regions in which cloud cover varies significantly between successive overpasses?
4. Are cloud cover estimates consistent for different regions of the same cloud climatology?
5. Are land surface retrievals such as the Normalized Difference Vegetation Index (NDVI) consistent with those measured previously at a given location.

These are just a few examples of the type of question that must be answered to be able to have some degree of confidence in the results.

To summarize, basic global verification processes include:

1. Internal consistency checks (i.g., view and zenith angle dependence of results and day-to-day cloud cover results).
2. Global and regional (i.e., cloud climatologies) analyses of cloud statistics over long time periods.
3. Comparisons with existing cloud climatologies (i.e., ISCCP, CLAVR, surface observations).
4. Comparison of surface property retrievals (i.e., NDVI) with PATHFINDER data sets.

Once some confidence has been gained in processing global imager data, the next task is to compare the results to independent observations. There are numerous problems involved in comparing satellite-derived results with ground-based lidars, radars and surface-based observations. For instance, it is important to account for the relatively small size of the lidar or radar field-of-view (FOV), as compared to the much larger satellite FOV. Also, lidars and radars may retrieve different cloud boundaries, depending upon their sensitivity to cloud effective particle size, optical depth, etc. Differences between remotely-sensed and ground-based estimates of cloud cover must be examined carefully without automatically assuming that only one value is correct. Similar cautions apply to surface observer estimations of cloud cover. Surface observers have a very different FOV. Cloud sides are observed not only by surface observers but also by the satellite sensors at the larger observing angles. Therefore, estimates may be differentially biased, depending upon cloud thickness.

#### Plan #1: Routine (Long-term) comparison of Satellite and Ground-Based Observations

For our purposes, the highest priority set of observations will be those where CERES cloud properties can be compared *routinely* to those obtained at a well-known surface site such as that provided by the Atmospheric Radiation Measurement program. Extended observations will be provided by the ARM sites, but not at all the locations we require according to the categories above.

These include a currently operational site (Southern Great Plains, specifically Oklahoma), a Tropical West Pacific site to be operational in 1996 (five islands north of Australia), and an Arctic site (north slope of Alaska) planned for 1997. The important point here is that CERES needs data for comparison over a long time period from sites placed in different cloud regimes. If algorithms are developed or tuned specifically to improve retrievals in one region, problems may occur in different regions. A second, and not inconsiderable, point to mention is that with routine measurements, one should expect that input data structures to change infrequently. That is, we do not have to work the problem of "spin-up" with a new data set involving new data formats and data structures, frequency of measurements, idiosyncrasies, etc. that are common to data collected during infrequent field programs.

Another source of cloud cover validation is the surface weather station reports collected by the NOAA National Meteorological Center (NMC). The NMC surface synoptic observations include cloud fraction (in octals) as well as information about cloud types and cloud layering. Besides surface synoptic observations, there is also a relatively new effort to compare ground observations of cloud cover with satellite observations using an Automated Surface Observing System (ASOS, Schreiner et al. 1993) over the continental United States.

Rossow et al (1993) reported that surface observations agreed with ISCCP cloud amounts to within 15% rms with biases of only a few percent. On the other hand, when measurements of small-scale, broken clouds were isolated for comparison, Rossow et al found rms difference between satellite and surface cloud amounts on the order of 25%, similar to the rms difference between ISCCP and LANDSAT determinations of cloud amount. Rossow et al found that detection errors were caused mainly by errors in clear-sky radiances or by incorrect radiance thresholds. This resulted in cloud amounts too low over land by about 10% (somewhat less in summer and somewhat more in winter), and approximately correct over the oceans. For the polar regions, the ISCCP cloud amounts were found to be 15%-25% low in summer and 5%-10% low in winter. It is proposed to perform a similar analysis of the CERES AVHRR cloud cover retrievals before launch. It can be expected that various regions (polar, deserts, mountains, regions of biomass burning, sunglint, coastal) may have quite dissimilar biases, as well as both seasonally and for day/night.

CERES will generate a global cloud climatology based upon the AVHRR results. These results will be compared with several other global cloud climatologies (including ISCCP and CLAVR). Geographical distributions of cloudiness, seasonal variations and day/night comparisons will be examined. Clear-sky maps will be generated from the CERES cloud detection algorithms. Clouds which are undetected by the algorithm may be identified by radiance variations they cause either spatially or temporally. Radiance changes are those that cause a variation between radiances measured at a specific place and time with estimates of radiance values that represent clear conditions (from a long-term clear-sky data base). Variations in derived NDVI values can be used in similar fashion. Long-term and seasonal NDVI values may be acquired from the PATHFINDER data set.

The sea surface temperature (SST) data sets also will be used for this purpose. Blended Analysis (Reynolds, 1988) combines the NOAA Multichannel SST (MCSST) retrieved from AVHRR with ship and buoy measurements to produce monthly mean maps on a  $2^{\circ}$  grid. The Comprehensive Ocean-Atmosphere Data Set (COADS) contains ship and buoy measurements of water temperatures below the surface. These need to be adjusted for surface temperatures. In the polar regions, sea ice surface temperatures may be compared with available arctic climatologies (Sch-

weiger and Key, 1992). On the other hand, over land the only available data sets for comparison of satellite derived near-surface temperatures are the 1-2m values reported by surface weather observers. Direct surface station reports at 3-h time intervals are available from the U.S. National Meteorological Center collection at NOAA in Asheville and the twice-daily U.S. Air Force analysis. In these cases, cloud contamination of the clear-sky SST or land surface temperature radiance values can be expected to cause an underestimate of cloud amount (except in the polar regions where cloud tops may be warmer than the surface).

The above analysis of radiance differences should be treated with caution, however. Radiance differences in low latitudes may be due to water vapor which would affect the SST retrievals but not the CERES cloud detections. In the high latitudes, radiance differences may be caused by smoothing in the blended data sets, particularly near strong currents. Rossow et al (1993) suggest that at high latitudes, an underestimate by 1K could cause an underestimate of cloud amounts by 5%. Furthermore, over land, emissivity is variable with both location and time, due to effects of vegetation and changing soil moisture content. Geographic variations in emissivity may be expected to produce variations in surface temperatures on the order of 2K, but larger variations over deserts.

#### Plan #2: Regional (short-term) comparison of Satellite with Ground-Based Observations

A number of field programs have addressed various aspects of cloud property retrieval. Instrumentation for these campaigns varies widely. It is only recently that radars have begun to complement lidars to determine cloud boundaries. Existing and future field experiments (FIRE, SCAR, SHEBA, TOGA\_COARE, CEPEX, ASTEX, ECLIPS, MCTEX, and others) will provide important validation for their particular climatic and background conditions; however, validation samples over mid-latitude ocean, mountains, deserts, and tropical land are still needed.

The typical field campaign has a duration of a month or less. Some of the drawbacks to using field mission data of short duration are that 1) data formats vary widely, 2) data quality is problematic, and 3) obtaining all of the necessary data sets for performing a comparison of ground-based with satellite retrievals may take years from the date of the experiment, depending upon the data policy in effect. The bottom line is that working with short-term field campaigns may be extremely time consuming for relatively little benefit. It is suggested that future campaigns be required to provide data in a timely fashion, with good documentation and with standard data formats.

#### Plan #3: Validation with Aircraft

Comparisons of satellite and ground-based observations will lead to significant deficiencies in particular regions. These regions include: polar, desert, mountains, coastal, and regions of biomass burning. In some of these regions the AVIRIS and MAS data may be used to improve and validate the algorithms. Thin cirrus may be detected using the 1.38um channel of both AVIRIS and MAS. MAS data taken over the Beaufort Sea and in Brazil will be used for the polar and biomass burning regions. And, AVIRIS data taken during the FIRE and ASTEX experiments will be used over land and ocean surfaces. Additional data taken during upcoming field experiments will be used in a similar fashion.

#### **4.1.3.2 Operational surface networks**

We anticipate using the following products in our pre-launch activities:

1. National Weather Service (NWS) global synoptic cloud observations
2. Ceilometer network (limited to continental U.S.)
3. Blended Analysis sea surface temperatures
4. COADS data set
5. Surface observer 3-h reports
6. DOE ARM data
7. Automated Surface Observing System

#### **4.1.3.3 Existing satellite data**

A list of the satellite data sets used in pre-launch activities are:

1. AVHRR
2. HIRS
3. GOES-8 and GOES-9
4. ISCPP cloud climatologies
5. CLAVR cloud climatologies
6. LITE
7. MAS and AVIRIS aircraft data

### **4.1.4 Post-launch Activities**

#### **4.1.4.1 Planned field experiments and studies**

The same approach as presented in Section 4.1.3.1 will be followed for post-launch activities. Since the cloud retrieval properties for the imager data are not going to be saved as an actual data product, selected regions will be saved daily for validation activities. The Version 1 list of selected regions includes both poles, North and South America, the coasts of Europe, persistent stratus regimes, the Tropical DOE ARM site and northern Australia, and a few other specific regions. These subsetted data sets will be produced through EOSDIS, and detailed analysis will be provided primarily by the CERES Co-Investigators.

#### **4.1.4.2 Other EOS-targeted coordinated field campaigns**

With the comparison of satellite and ground-based observations of cloud boundaries/ cloud cover, according to the strategies previously outlined, deficiencies will still exist over midlatitude oceans, mountains, deserts, polar regions and tropical land, especially in regions of heavy biomass



burning. To fill data-sparse gaps in our sampling, it would be beneficial to plan field campaigns for these areas, or to join already planned field campaigns.

#### **4.1.4.3 Needs for other satellite data**

ASTER high spatial resolution data will be utilized for global cloud cover validation. As described in Section 4.1.2.2, ASTER data will be acquired for the 40 global cloud climatologies. A total of 100 independent samples are required for each of the 40 climatologies and both for day and night, for a total of 8000 scenes (60km x 60km). It will be necessary to arrange with the ASTER team to acquire the data consistent with their duty cycle. While the ARM sites and NOAA NMC surface synoptic observations will provide long-term, stable data sets for validation, we do not anticipate having the required sampling (see section 4.1.2.2) for all global cloud regimes. To fill in the gaps, ASTER/MODIS comparisons will provide some insight as to how the CERES algorithms are working, much like the current LANDSAT studies (e.g., Wielicki and Parker 1992), in regions where surface observations are sparse.

Another very useful set of satellite measurements for validation purposes would be lidar/radar observations, such as LITE. To date LITE has been flown only once, and GOES-8 was not operational at that time and NOAA-11 ceased operations two days after the launch of LITE. Furthermore, only two LITE/NOAA-12 coincidences are available.

#### **4.1.4.4 In-situ measurement needs at calibration/validation sites**

#### **4.1.4.5 Needs for instrument development**

#### **4.1.4.6 Geometric registration site**

#### **4.1.4.3 Intercomparisons (multi-instrument)**

### **4.1.5 Implementation of validation results in data production**

#### **4.1.5.1 Approach**

We anticipate that validation of clear-sky radiances, cloud detection and cloud property retrievals will take place at the CERES SCF or at the investigator home institutions. While some of the global mapping functionality can be automated, most of the effort described in this document requires interaction with an investigator. The investigators will need ready access to cloud boundary information from each of the ARM sites, to other sites that are operationally providing

cloud boundary information, to the ASTER cloud masks, as well as to the subsetting data sets of retrieved cloud properties. We also need rapid access to the NOAA NMC synoptic observations in a standard format such as HDF.

#### 4.1.5.2 Role of EOSDIS

EOSDIS will have an important but limited role in this process. For the retrieved cloud parameters listed in Table 4.4-4 of the CERES Subsystem 4.4, entitled "Convolution of imager cloud properties with CERES footprint point spread function," the volume of one hour of processed imager data is approximately 600MB. These retrievals are not a data product, but they are subsequently convolved with CERES footprints. It would be impractical to save all of the output from processing each hour of imager data. Rather, we propose to subset the output data stream by choosing a number of regions around the globe that are useful for validation purposes.

The data center responsible for processing CERES data should be tasked to routinely save the data from the prescribed set of regions designated by the CERES team. The saved data should be considered to be a temporary data product. Cloud boundary data from the sources listed in this document also should be available from and saved by EOSDIS.

#### 4.1.5.3 Plans for archival of validation data

The set of CERES subsetting regions, corresponding ASTER imager data, surface observational data and aircraft data all should be saved on DAT or Exabyte tape and be provided to investigators for analysis at their SCFs.

#### 4.1.6 List of Acronyms

ARM	Atmospheric Radiation Measurement Program
ASTER	Advanced Spaceborne Thermal Emission and Reflectance Radiometer
ASTEX	Atlantic Stratocumulus Transition Experiment
AVHRR	Advanced Very High Resolution Radiometer
COADS	Comprehensive Ocean-Atmosphere Data Set
ECLIPS	Experimental Cloud Lidar Pilot Study
FIRE	First ISCCP Regional Experiment
GOES	Geostationary Orbiting Environmental Satellite
HIRS	High-resolution Infrared Radiometer Sounder
ISCCP	International Satellite Cloud Climatology Experiment
LITE	Lidar in Space Technology Experiment
MAS	MODIS Airborne Simulator
MODIS	Moderate resolution Imaging Spectrometer
NMC	National Meteorological Center
SHEBA	Surface HEat Budget in the Arctic
VIRS	Visible and Infrared Scanner

### 4.1.7 References

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### 4.1.8 Tables

**Table 1: GLOBAL CLOUD CLIMATOLOGIES**

Region	Description	Location	Seasonal Change in Cloud Amt	Dominant Cloud Type	Diurnal Variation in Cloud Amt
01	Essentially Clear	Major Desert Area	Small	-----	Small
02	Little Cloudiness	Sub-Desert Area	Small	-----	Small
03	Tropical Cloudy	Near Equator	Small	Convective	Large
04	Tropical Moderate Cloudiness	N or S of Region 3	Small	Convective	Large
05	Desert Marine	Over Ocean off W. Coast	Small	Stratiform	Large

**Table 1: GLOBAL CLOUD CLIMATOLOGIES**

Region	Description	Location	Seasonal Change in Cloud Amt	Dominant Cloud Type	Diurnal Variation in Cloud Amt
06	Desert Marine Cloudy Winter	Over Ocean W. of Peru	Extreme	Stratiform	Large
07	Desert Marine Cloudy Summer	Over Ocean W. of Baja Calif.	Extreme	Stratiform	Large
08	Mid-latitude Clear Summer	North America	Extreme	Synoptic Scale	Small
09	Mid-Latitude Cloudy Summer	North America & Asia	Moderate	Synoptic Scale	Small
10	High Latitude Clear Winter	Asia & North America	Extreme	Synoptic Scale	Small
11	Mid-Latitude Land	Northern Hemisphere	Moderate	Synoptic Scale	Small
12	Tropical CLOUDy Summer	North of Region 3	Moderate	Convective	Large
13	Mid-Latitude Ocean	Northern Hemisphere	Moderate	Synoptic Scale	Small
14	High Latitude Ocean	Northern Hemisphere	Moderate	Synoptic Scale	Small
15	Polar	Northern Hemisphere	Small	Synoptic Scale	Small

**Table 1: GLOBAL CLOUD CLIMATOLOGIES**

Region	Description	Location	Seasonal Change in Cloud Amt	Dominant Cloud Type	Diurnal Variation in Cloud Amt
16	Tropical Seasonal Change	North of Region 3	Extreme	Convective	Large
17	Tropical Clear Winter	Northern Hemisphere near Region 16	Moderate	Convective	Large
18	Mediterranean	Northern Hemisphere Europe, West North America	Extreme	Convective	Small
19	Sub-Tropical	Northern Hemisphere ~30N	Moderate	Convective Synoptic Scale	Large
20	Sub-Tropical Ocean	Northern Hemisphere ~30N	Moderate	Convective Synoptic Scale	Small
21	Tropical Cloudy Summer	South of Region 3	Moderate	Convective	Large
22	Mid-Latitude Ocean	Southern Hemisphere	Moderate	Synoptic Scale	Small
23	High Latitude Ocean	Southern Hemisphere	Moderate	Synoptic Scale	Small
24	Polar	Southern Hemisphere	Small	Synoptic Scale	Small
25	Tropical Seasonal Change	South of Region 3	Extreme	Convective	Large

**Table 1: GLOBAL CLOUD CLIMATOLOGIES**

Region	Description	Location	Seasonal Change in Cloud Amt	Dominant Cloud Type	Diurnal Variation in Cloud Amt
26	Tropical Clear Winter	South of Region 25 Africa Australia	Moderate	Convective	Large
27	Mediterranean	Southern Hemisphere Australia Chile	Extreme	Convective	Small
28	Sub-Tropical Land	Southern Hemisphere ~30S	Moderate	Convective Synoptic Scale	Large
29	Sub-Tropical Ocean	Southern Hemisphere ~30S	Moderate	Convective Synoptic Scale	Small